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PROGRESS REPORT ON NASA-SPONSORED RESEARCH
(PLANETARY MATERIALS AND GEOCHEMISTRY)

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Lunar sample research is a continuation of the boldest, most historic, and most successful of NASA's missions (i.e., Apollo). Lunar sample research has provided the principal ground-truth for the earliest, and most energetic, processes associated with global planetary differentiation (e.g., magma oceans). Lunar sample research continues to provide fundamental scientific information about the origin of planetary crusts, mantles, and cores, including the earliest history of Earth (e.g., giant impact that generated the Moon).

My research has involved the geochemical compositions of lunar glasses, both impact and volcanic varieties, in order to constrain the compositions of the lunar highlands crust and the deep lunar mantle, respectively. Experimental petrology at high pressures and temperatures on selected lunar volcanic glass compositions has been important for constraining the depths of origin of these magmatic samples. In addition, high-precision methods have been developed for analysis of several trace elements (e.g., S, Cl, V, Mn, Ni) in the volcanic glasses. The principal advances in these efforts have centered on the composition, origin, and implications of lunar volcanic glasses.

This research has succeeded in identifying twenty-four compositional varieties of lunar volcanic glass from the six Apollo landing sites. Their compositions have been defined by high-precision electron microprobe analyses, as well as by instrumental neutron activation analysis in some instances. These volcanic glasses are of scientific significance because they are now generally recognized within the lunar science community to represent samples of *primary* magmas from the lunar mantle. Experimental data on these compositions indicate that they may be the products of partial melting processes at about 500 kilometers beneath the lunar surface. As such, these volcanic glasses provide the scientific community with the clearest best geochemical and petrological window into the deep lunar interior of all samples returned from the Moon. The large diversity of chemical compositions represented among the twenty-four varieties of volcanic glass have provided strong constraints on current models for the composition and structure of the deep lunar interior. In addition, the process of global differentiation that affected the Moon during the first 200-300 million years has become better understood as a result of this knowledge. Solid state convection and negatively buoyant magmas are two of the major processes that determined the present state of the lunar interior. Furthermore, the enigmatic volatiles associated with the eruption of all varieties of volcanic glass has recently become a focus of interest for this research. These volatiles define a paradox that conflicts with the origin of the Moon by a giant impact onto the early Earth.

In summary, these volcanic glasses have yielded the following process-related discoveries:

- Diverse population of primary magmas reflecting a compositionally diverse mantle.
- Buoyantly driven melt segregation and the prospects for negative buoyancy at low pressure.
- Simultaneous eruption of compositionally distinct magmas not before seen on the Moon.
- 500-kilometer depth of origin and rapid ascent of primary magma.
- Enigmatic association with volatile-rich component in the lunar mantle.
- Constraints on global differentiation processes and solid-state redistribution of products.
- Complex processes of volatilization and sublimation of volcanic volatiles during eruption.
- Processes controlling the oxidation state of the deep lunar mantle.

Other results from this research include: (a) the role of Soret diffusion in generating systematic heterogeneities within tektite glass; (b) constraints on the source materials of tektites using compositional systematics of these natural glasses; (c) experimental calibration of a Cr-oxygen barometer for estimating the oxidation state of magmas erupted on the Earth and Moon; (d) compositional constraints on the source regions of lunar meteorites; and (e) estimates on the bulk composition of the Moon and implications for its origin.

During this NASA-sponsored research, the author ... has served on three NASA panels, convened a scientific workshop, and been a key-note/invited speaker at numerous NASA+LPI-sponsored conferences and workshops. These activities, and others, are detailed in the abbreviated vita that is attached to this document. Publications and abstracts that have resulted from this research support from NASA are also listed.

VITA: John W. Delano

PERSONAL DATA

Born December 19, 1947; Wichita Falls, TX. Married.
U.S. Citizen.

EMPLOYER

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EDUCATION

Ph.D. Geochemistry -- State University of New York at Stony Brook, 1977.

PROFESSIONAL EXPERIENCE

Associate Professor - State University of New York at Albany, 1988 to present.
NASA Lunar Sample Principal Investigator - 1984 to present.
Consultant to NASA -
Lunar and Planetary Sample Team (LAPST), 1989-1992 (Chairman, 1991-1992);
Planetary Materials and Geochemistry Management Operations Group, 1993-1994;
Lunar and Planetary Geoscience Review Panel, 1994-1996.
Consortium for Advanced Radiation Sources, member, 1990-1993.
Speaking tour sponsored by Mineralogical Society of Canada (March-April 1991).
Convenor of NASA-sponsored workshop (Oct. 10-12, 1989) entitled "Lunar Volcanic Glasses: Scientific and Resource Potential".
Assistant Professor - State University of New York at Albany, 1982-1988.
NASA Lunar Sample Co-Investigator - 1979-1984.
Associate Editor: Proceedings of the 12th Lunar and Planetary Science Conference, 1981.
Post-Doctoral Research Associate - State University of New York at Stony Brook, 1980-1982.
Post-Doctoral Research Fellow - Australian National University, 1977-1980.
Research Assistant - State University of New York at Stony Brook, 1973-1976.
Teaching Assistant - Cornell University, 1969-1971.
Field Assistant - Minnesota Geological Survey, summer 1970.

PROFESSIONAL SOCIETIES

Geochemical Society
Geological Society of America

RESEARCH INTERESTS

Chemical compositions of lunar volcanic glasses; chemical compositions of melt inclusions in quartz phenocrysts for stratigraphic and tectonic investigations; sedimentary geochemistry.

PUBLICATIONS

Delano J.W. and Livi K. (1981) Lunar volcanic glasses and their constraints on mare petrogenesis. Geochim. Cosmochim. Acta, 45, p. 2137-2149.

Delano J.W., Lindsley D.H., and Rudowski R. (1981) Glasses of impact origin from Apollo 11, 12, 15, and 16: Evidence for volatile-loss and mare/highland mixing. Proc. Lunar Planet. Sci. Conf. 12th, p. 339-370.

Delano J.W., Lindsley D.H., Ma M.-S., and Schmitt R.A. (1982) The Apollo 15 yellow impact glasses: Chemistry, petrology, and exotic origin. Proc. Lunar Planet. Sci. Conf. 13th, p. A159-A170.

Chen H.-K., Delano J.W., and Lindsley D.H. (1982) Chemistry and phase relations of VLT volcanic glasses from Apollo 14 and Apollo 17. Proc. Lunar Planet. Sci. Conf. 13th, p. A171-A181.

Delano J.W. and Lindsley D.H. (1982) Chemical systematics among the moldavite tektites. Geochim. Cosmochim. Acta, 46, p. 2447-2452.

Delano J.W. and Lindsley D.H. (1983) Mare glasses from Apollo 17: Constraints on the Moon's bulk composition. Proc. Lunar Planet. Sci. Conf. 14th, p. B3-B16.

Spangler R.R. and Delano J.W. (1984) History of the Apollo 15 yellow impact glass and sample 15426 and 15427. Proc. Lunar Planet. Sci. Conf. 14th, p. B478-B486.

Spangler R.R., Warasila R., and Delano J.W. (1984) ^{39}Ar-^{40}Ar ages for the Apollo 15 green and yellow volcanic glasses. Proc. Lunar Planet. Sci. Conf. 14th, p. B487-B497.

Delano. J.W. (1986) Abundances of cobalt, nickel, and volatiles in the silicate portion of the Moon. In Origin of the Moon (W.K. Hartmann, R.J. Phillips, and G.J. Taylor, eds.), p. 231-247. Lunar and Planetary Institute, Houston.

Delano. J.W. (1986) Pristine lunar glasses: Criteria, data, and implications. Proc. Lunar Planet. Sci. Conf. 16th, D201-D213.

Arculus R.J. and Delano J.W. (1987) Oxidation state of the upper mantle: Present conditions, evolution, and controls. In Mantle Xenoliths (P.H. Nixon, ed.), p. 589-602. John Wiley & Sons Ltd., London.

Delano J.W. (1988) Apollo 14 regolith breccias: Different glass populations and their potential for charting space/time variations. Proc. Lunar Planet. Sci. Conf. 18th, p. 59-65.

Hughes S.S., Delano J.W., and Schmitt R.A. (1988) Apollo 15 yellow-brown volcanic glass: Chemistry and petrogenetic relations to green volcanic glass and olivine-normative mare basalts. Geochim. Cosmochim. Acta, 52, p. 2379-2391.

Delano J.W., Bouska V., and Randa Z. (1988) Geochemical constraints on the source-materials of moldavite tektites. Proc. Second Intern. Conf. Natural Glasses (J. Konta, ed.), p. 221-230. Charles University, Prague, Czechoslovakia.

Jones J.H. and Delano J.W. (1989) A three component model for the bulk composition of the Moon. Geochim. Cosmochim. Acta, 53, p. 513-527.

Delano J.W. (1989) Densification of mantle-derived liquids in the Earth's moon: Implications for the Earth and other terrestrial-type objects. NASA Planetary Geosciences Annual Report.

Hughes S.S., Delano J.W., and Schmitt R.A. (1989) Petrogenetic modeling of 74220 high-Ti orange volcanic glasses and the Apollo 11 and 17 high-Ti mare basalts. Proc. Lunar Planet. Sci. Conf. 19th, p. 175-188.

Delano J.W. and Lindsley D.H. (1989) Chemical systematics among the moldavite tektites: Reply to W. von Engelhardt. Geochim. Cosmochim. Acta, 53, p. 2447-2448.

Hughes S.S., Delano J.W., and Schmitt R.A. (1990) Chemistries of individual mare volanic glasses: Evidence for distinct regions of hybridized mantle and a KREEP component in Apollo 14 magmatic sources. Proc. Lunar Planet. Sci. Conf. 20th, p. 127-138.

Delano J.W. (1990) Buoyancy-driven melt segregation in the Earth's moon, I. Numerical results. Proc. Lunar Planet. Sci. Conf. 20th, p. 3-12.

Righter K., Arculus R.J., Delano J.W., and Paslick C. (1990) Electrochemical measurements and thermodynamic calculations of redox equilibria in pallasite meteorites: Implications for the eucrite parent body. Geochim. Cosmochim. Acta, 54, p. 1803-1815.

Delano J.W. (1991) Major-element compositions of impact glasses from lunar meteorites (ALHA81005; MAC88105) and Apollo 16 regolith (64001): A comparison. Geochim. Cosmochim. Acta, 54, p. 3019-3029.

Taylor G.J., Warren P., Ryder G., Delano J., Pieters C., and Lofgren G. (1991) Lunar Rocks, in Lunar Sourcebook: A User's Guide to the Moon (G. Heiken, D. Vaniman, and B.M. French, eds.), p. 183-284. Cambridge University Press, New York. 736 pp.

Delano J. W. (1994) Liquid immiscibility and Soret diffusion in Australasian tektites. Geochim. Cosmochim. Acta, submitted.

Ryder G., Delano J. W., Warren P. and Dalrymple B. (1994) An impact glass spherule from the Apollo 15 landing site and singular mare basalt at the impact target. Geochim. Cosmochim. Acta, submitted.

ABSTRACTS

Delano J.W. and Livi K. (1981) Mare volcanic glasses: A tale of two arrays. Lunar Planet. Sci.-XII, p. 226-228. Lunar and Planetary Institute, Houston.

Delano J.W. (1981) Major-element chemistry of Apollo 11 volcanic glasses. Lunar Planet. Sci.-XII, p. 214-216. Lunar and Planetary Institute, Houston.

Delano J.W. (1981) Major-element compositions of high-titanium volcanic glasses from Apollo 14. Lunar Planet. Sci.-XII, p. 220-222. Lunar and Planetary Institute, Houston.

Delano J.W. (1981) Major-element compositions of volcanic green glasses from Apollo 14. Lunar Planet.Sci.-XII, p. 217-219. Lunar and Planetary Institute, Houston.

Delano J.W., Lindsley D.H., and Rudowski R. (1981) Glasses of impact origin from Apollo 11 and Apollo 12: Evidence for volatile-loss and mare/highland mixing. Lunar Planet. Sci.-XII, p. 223-225. Lunar and Planetary Institute, Houston.

Delano J.W., Lindsley D.H., Ma M.-S., and Schmitt R.A. (1982) Petrology and trace-element chemistry of Apollo 15 yellow impact glasses. Lunar Planet. Sci.-XIII, p. 166-167. Lunar and Planetary Institute, Houston.

Delano J.W. and Lindsley D.H. (1982) Chromium, nickel, and titanium abundances in 74275 olivines: More evidence for a high-pressure origin of high-titanium mare basalts. Lunar Planet. Sci.-XIII, p. 160-161. Lunar and Planetary Institute, Houston

Chen H.-K., Delano J.W., and Lindsley D.H. (1982) Liquidus-phase relations of the Apollo 14 and Apollo 17 VLT volcanic glasses. Lunar Planet. Sci.-XIII, p. 84-85. Lunar and Planetary Institute, Houston.

Delano J.W., Lindsley D.H., and Glass B.P. (1982) Nickel, chromium, and phosphorus abundances in HMg and bottle-green microtektites from the Australasian and Ivory Coast strewnfields. Lunar Planet. Sci.-XIII, p. 164-165. Lunar and Planetary Institute, Houston.

Delano J.W. and Lindsley D.H. (1982) New data on the fractionation trend in the Apollo 15 volcanic green glasses: Groups B, C. Lunar Planet. Sci.-XIII, p. 162-163. Lunar and Planetary Institute, Houston.

Delano J.W. and Lindsley D.H. (1982) Chemical systematics among the moldavite tektites. Lunar Planet. Sci.-XIII, p. 158-159. Lunar and Planetary Science Institute, Houston.

Delano J.W. and Lindsley D.H. (1982) Additional varieties of volcanic glasses from Apollo 12 and Apollo 17. Geol Soc. Amer., Abstracts with Programs, 14, p. 474.

Delano J.W. (1982) Volatiles in the Earth's Moon. Planetary Volatiles Conference, p. 27-28. Lunar and Planetary Institute, Houston.

Delano J.W. (1982) The early evolution of the Moon from mare basaltic liquids. In Workshop on Pristine Highlands Rocks and the Early History of the Moon, p. 36-43. Lunar and Planetary Institute, Houston. LPI Tech. Rep. 83-02.

Delano J.W. and Lindsley D.H. (1983) Indigenous lunar volatiles in mare volcanic glasses. Lunar Planet. Sci.-XIV, p. 154-155. Lunar and Planetary Institute, Houston.

Delano J.W. and Lindsley D.H. (1983) Volcanic glasses from Apollo 17. Lunar Planet. Sci.-XIV, p. 156-157. Lunar and Planetary Institute, Houston.

Delano J.W. (1984) "Genesis glass": In search of the holy grail. Lunar Planet. Sci.-XV, p. 216-217. Lunar and Planetary Institute, Houston.

Delano J.W. (1984) Vesicles in four varieties of Apollo 15 volcanic glass. Lunar Planet. Sci.-XV, p. 218-219. Lunar and Planetary Institute, Houston.

Delano J.W. (1984) Abundances of Ni, Cr, Co, and major elements in the silicate portion of the Moon: Constraints from primary lunar magmas. Conference on the origin of the Moon, p. 15. Lunar and Planetary Institute, Houston.

Delano J.W. (1985) Mare volcanic glasses, I: Major-element data. Lunar Planet. Sci.-XVI, p. 177-178. Lunar and Planetary Institute, Houston.

Delano J.W. (1985) Mare volcanic glasses, II: Abundances of trace Ni and the composition of the Moon. Lunar Planet. Sci.-XVI, p. 179-180. Lunar and Planetary Institute, Houston.

Delano J.W. and Stone K. (1985) Siderophile elements in the Earth's upper mantle: Secular variations and possible cause for their overabundances. Lunar Planet. Sci.-XVI, p. 181-182. Lunar and Planetary Institute, Houston.

Delano J.W. and Stone K. (1985) Siderophile elements in the Earth's upper mantle: Limits on continuous core-formation. EOS, 66, p. 419.

Delano J.W. (1986) A new aspect of Apollo 14 regolith breccias: Different glass populations and their potential for charting space/time variations. Lunar Planet. Sci.-XVII, p. 168-169. Lunar and Planetary Institute, Houston.

Fernandez M.M. and Delano J.W. (1986) Discriminant analysis of the pristine lunar glasses: Implications for a magma ocean. Lunar Planet. Sci.-XVII, p. 224-225. Lunar and Planetary Institute, Houston.

Delano J.W., Bouska, V., and Fernandez, M.M. (1986) Chemical variations among the moldavite tektites: Major-element data. Lunar Planet. Sci.-XVII, p. 170-171. Lunar and Planetary Institute, Houston.

Delano J.W., Verplanck L., Hughes S.S., and Schmitt R.A. (1986) Warning to lunar glass students: Possible contamination from colored ovoids produced by gas lighters - Misch metal flints. Lunar Planet. Sci.-XVII, p. 174-175. Lunar and Planetary Institute, Houston.

Delano J.W., Hughes, S.S., and Schmitt, R.A. (1986) Collaborative study of the Apollo 15 pristine yellow/brown glasses: An interim report. Lunar Planet. Sci.-XVII, p. 172-173. The Lunar and Planetary Institute, Houston.

Hughes S.S., Delano J.W., and Schmitt R.A. (1987) Integrated petrogenetic models of Apollo 15 yellow/brown glass, green glass and olivine mare basalt, consistent with the magma ocean -- cumulate hypotheses. Lunar Planet. Sci.-XVIII, p. 445-446. Lunar and Planetary Institute, Houston.

Delano J.W., Bouska V., and Randa Z. (1987) Geochemically inferred redox state for the target materials of terrestrial impact glasses. Lunar Planet. Sci.-XVIII, p. 233-234. Lunar and Planetary Institute, Houston.

Jones J.H. and Delano J.W. (1987) A three component model for the bulk composition of the Moon. Lunar Planet. Sci.-XVIII, p. 468-469. Lunar and Planetary Institute, Houston.

Delano J.W., Hughes S.S., Verplanck P.L., and Schmitt R.A. (1987) Multi-element abundances of individual mare volcanic glasses by collaborative electron microprobe and neutron activation analyses: Interim report #2. Lunar Planet. Sci.-XVIII, p. 235-236. Lunar and Planetary Institute, Houston.

Delano J.W. (1987) Glass: A source of data leading to constraints on the volcanic, impact, and atmospheric histories of Mars. Mars Sample Return Science Workshop. LPI Tech. Report 88-07. p. 63-64. Lunar and Planetary Institute, Houston.

Jones J.H. and Delano J.W. (1988) Fractional crystallization of the lunar magma ocean, the bulk composition of the Moon, and comparison to the Earth. Lunar Planet. Sci.-XIX, p. 563-564. Lunar and Planetary Institute, Houston.

Hughes S.S., Delano J.W., and Schmitt R.A. (1988) Chemistry of 74220 mare volcanic glass: Implications for their magmatic source composition. Lunar Planet. Sci. - XIX, p. 517-518. Lunar and Planetary Institute, Houston.

Delano J.W., Hughes S.S., and Schmitt R.A. (1988) Inter-element correlations among mare basalts and pristine lunar glasses. Lunar Planet. Sci.-XIX, p. 271-272. Lunar and Planetary Institute, Houston.

Delano J.W. (1988) Depths of mare source-regions: Limits imposed by buoyancy-driven melt segregation. Lunar Planet. Sci.-XIX, p. 269-270. Lunar and Planetary Institute, Houston.

Delano J.W., Hughes, S.S., and Schmitt R.A. (1988) Ultramafic magmas on the Moon: Implications for mantle processes and composition. EOS, 69, p. 392.

Jones J.J. and Delano J.W. (1988) A convergence of models for the bulk composition of the Moon. EOS, 69, p. 393.

Hughes S.S., Delano J.W., and Schmitt R.A. (1989) Trace element signatures in mare volcanic and impact-melt glasses from Apollo 14, 15, 16 and 17. Lunar Planet. Sci.-XX, p. 432-433. Lunar and Planetary Insitute, Houston.

Hughes S.S., Delano J.W., and Schmitt R.A. (1989) Trace element chemistries of 74241 and 79221 mare volcanic glasses. Lunar Planet. Sci.-XX, p. 430-431. Lunar and Planetary Institute, Houston.

Delano J.W. (1989) Buoyancy-driven melt segregation in the Earth's moon. Lunar Planet. Sci.-XX, p. 240-241. Lunar and Planetary Institute, Houston.

Righter K., Arculus R.J., and Delano J.W. (1989) Redox equilibria in pallasite meteorites and the eucrite parent body (EPB). Lunar Planet. Sci.-XX, p. 906-907. Lunar and Planetary Institute, Houston.

Delano J.W. (1990) Constraints on the highlands source-area of lunar meteorite ALHA 81005 using chemical compositions of glasses. Lunar Planet. Sci.-XXI, p. 276-277. Lunar and Planetary Institute, Houston.

Delano J.W. (1990) Experimental constraints on the oxidation state of the lunar mantle. Lunar Planet. Sci.-XXI, p. 278-279. Lunar and Planetary Institute, Houston.

Delano J.W., Liu Y.-G., and Schmitt R.A. (1990) Geochemistry of Apollo 11 impact glasses: Regolith compositions. Lunar Planet. Sci.-XXI, p. 280-281. Lunar and Planetary Institute, Houston.

Delano J.W. (1991) Major-element compositions of glasses in Apollo 16 core 64001: Constraints on the mare component. Lunar Planet. Sci.-XXII, p. 303-304. Lunar and Planetary Institute, Houston.

Delano J.W., Sutton S.R., and Smith J.V. (1991) Lunar volcanic glasses: Trace element abundances in individual spheres using synchrotron x-ray fluorescence. Lunar Planet. Sci.-XXII, p. 311-312. Lunar and Planetary Institute, Houston.

Delano J.W. (1991) Trace abundances of phosphorus (P) in pristine lunar glasses. Lunar Planet. Sci.-XXII, p. 307-308. Lunar and Planetary Institute, Houston.

Delano J.W., Liu Y.-G., and Schmitt R.A. (1991) Geochemistry of Apollo 17 impact glasses: Regolith compositions. Lunar Planet. Sci.-XXII, p. 309-310. Lunar and Planetary Institute, Houston.

Delano J.W. (1991) "Pyroxenite xenolith" in mare basalt 10050: Evidence of thermal erosion by mare volcanics? Lunar Planet. Sci.-XXII, p. 305-306. Lunar and Planetary Institute, Houston.

Delano J.W., Liu Y.-G., Schmitt R.A., and Bouska V. (1992) Geochemistry and origin of moldavite tektites. Lunar Planet. Sci.-XXIII, p. 305-306. Lunar and Planetary Institute, Houston.

Delano J.W. (1992) Australite flanges as flight data recorders. Lunar Planet. Sci.-XXIII, p. 301-302. Lunar and Planetary Institute, Houston.

Delano J.W. (1992) Major-element compositions of glasses in Apollo 16 cores 60014 (Station 10) and 64001 (Station 4). Lunar Planet. Sci.-XXIII, p. 303-304. Lunar and Planetary Institute, Houston.

Hanson B.Z. and Delano J.W. (1992) Experimental data bearing on the oxidation state of chromium and vanadium in mafic volcanics. Lunar Planet. Sci.-XXIII, p. 481-482. Lunar and Planetary Institute, Houston

Delano J.W. and McGuire J. (1992) Abundances of sodium, sulfur, and potassium in lunar volcanic glasses: Evidence for volatile-loss during eruption. Geology of the Apollo 17 Landing Site (G. Ryder, P. Spudis, and H. Schmitt, eds.), p. 7-9. LPI Tech. Report 92-09, Part 1. Lunar and Planetary Institute, Houston.

Delano J.W. (1992) Mare volcanism in the Taurus-Littrow region. Geology of the Apollo 17 Landing Site (G. Ryder, P. Spudis, and H. Schmitt, eds.), p. 5-7. LPI Tech. Report 92-09, Part 1. Lunar and Planetary Institute, Houston.

Delano J. W. (1993) Compositional heterogeneity within a dumbbell-shaped Apollo 15 green glass: Evidence for simultaneous eruption of different magmas. Lunar Planet. Sci.-XXIV, p. 393-394. Lunar and Planetary Institute, Houston.

Delano J. W. (1993) Oxidation state of the Earth's upper mantle during the last 3800 million years: Implications for the origin of life. Lunar Planet. Sci.-XXIV, p. 395-396. Lunar and Planetary Institute, Houston.

Delano J. W., Liu Y.-G., and Schmitt R. A. (1993) Soret diffusion: A possible cause of compositional heterogeneity within tektites. Lunar Planet. Sci.-XXIV, p. 397-398. Lunar and Planetary Institute, Houston.

Delano J. W., Hanson B. Z., and Watson E. B. (1994) Abundance and diffusivity of sulfur in lunar picritic magmas. Lunar Planet. Sci.-XXV, p. 325-326. Lunar and Planetary Institute, Houston.

Jones J. H., Hanson B. Z., McKay G. C., Jurewicz A. J. G., Delano J. W., and Mittlefehldt D. W. (1994) The compositional similarity between Sioux County and experimentally produced partial melts of the Murchison chondrite favors a partial melting origin for primitive eucrites. Lunar Planet. Sci.-XXV, p. 639-640. Lunar and Planetary Institute, Houston.

Hanson B. and Delano J. W. (1994) Electron microprobe analyses of low vanadium basalt glasses. Lunar Planet. Sci.-XXV, p. 505-506. Lunar and Planetary Institute, Houston.

Delano J. W. (1994) Oxidation state of the martian mantle from analysis of basaltic rocks. Mars Surveyor: Science Objectives/Measurement Requirements Workshop, NASA Jet Propulsion Laboratory, Pasadena, CA, (in press).